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BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

CONCENTRATION OF SULFUR COMPOUNDS IN CITY AIR

BY

L. R. BURDICK AND J. F. BARKLEY

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CONCENTRATION OF SULFUR COMPOUNDS IN CITY AIR[1]

By L. R. Burdick[2] and J. F. Barkley[3]

Sulfur compounds have long been recognized as damaging pollutants of he air. A number of investigations have been made to determine the amount f such compounds existing in the air of various cities; moreover, some tudy has been given to the conditions affecting the concentrations. This aper summarizes published investigations and includes a bibliography on the ubject.

The methods of obtaining data have differed as to the type of sampling, nalysis procedure, hour of sampling, number of locations, and number of eterminations made. Sampling methods include both the continuous type, overing a day or a number of days, and what can be considered the "snap" ype, covering very short periods. Continuous sampling has given data epresenting the average concentration at the location chosen but no informa-ion regarding variations from hour to hour, and none that might be said to epresent the average for a city. The snap-sampling method, while not giving true average for any one location or area, has in some instances made ailable data regarding variations of concentration during different hours the day and at various locations or zones within the area chosen. though the sulfur compounds in the air may include sulfur dioxide, sulfur ioxide, hydrogen sulfide, and organic compounds of sulfur, most investiga-rs report on the basis of sulfur dioxide. This gas unites with moisture form sulfurous acid.

SUMMARY OF INVESTIGATIONS

Cities of the United States

icago, Ill., 1937

Chambers, Singh, and Deutch (1)[4] have reported the results of a pre-inary survey of the air over Chicago. 271 determinations of snap samples re made at various locations and hours during the period from January 27, 37, to April 16, 1937. The analysis procedure was to absorb the sulfur oxide in slightly acidulated distilled water containing 1 cc. of 30 percent

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Figures in parentheses refer to items in the bibliography at the end of this paper.

hydrogen peroxide per 2-1/2 liters, measuring the volume of sample by a meter, and titrating the absorbing solution to neutrality with NaOH before and after the drawing of the sample. Methyl red containing Guinea Green dye was used as an indicator. Wind velocity and direction, barometer, relative humidity, outside temperature, and weather were noted for each determination. The maximum sulfur dioxide found was 3.16 p. p. m. by volume at the center of the concourse of a railroad station. Zero concentrations were noted occasionally at other locations. The survey showed the following concentrations: The "Loop", 0.43 p. p. m.; manufacturing areas, usually lower than the "Loop" area but as high as 0.8 or 1.0 p. p. m. on foggy or gusty days; congested residential areas, 0.30 p. p. m. and often above 0.5 p. p. m. with high relative humidity; less-congested residential areas, up to 0.15 p. p. m. depending upon wind direction; near central generating stations, 0.29 p. p. m.; near locomotive roundhouses, 0.54 p. p. m.; near stock yards, 0.2 p. p. m. or more.

Pittsburgh, Pa., 1927-32

Meiter and Traubert (2) made single daily analyses, except on Sundays and holidays, of the air at the Pittsburgh Experiment Station of the Bureau of Mines from August 11, 1927, to August 11, 1928. Snap sampling was done 40 feet above ground level, on the roof of the building. Analyses were by the general method developed by the Selby Smelter Commission (3). 304 determinations were made during the year, most of them between 8:00 and 10:00 a. m. Wind velocity and direction and smoke fog and cloud conditions were observed at the time of sampling. Concentrations ranged from 0.0 to 1.1 p. p. m. sulfur dioxide, the maximum occurring in October during unusually dense fog and smoke. Monthly averages ranged from 0.02 p. p. m. in July to 0.67 p. p. m. in October. The yearly average was 0.16 p. p. m. During thi work the concentration tended to be higher on foggy or smoky days and lower on days of high wind velocity.

Betz, Holden, and Handy (4) made sulfur dioxide determinations at a location about one-half mile from the business district in a rather thickly populated section. Snap samples were taken 75 feet above the ground. 607 tests were made on 307 days between July 1, 1931, and June 30, 1932. As often as possible, tests were made at 9 a. m. and 3 p. m. Conditions differing from those under which Meiter and Traubert made their investigation in 1927-28 (2) were, a lower altitude, a position nearer the center of the city, a much more thickly populated district farther from railroads, and less industrial activity. Analyses were made by the method of McKay and Ackerman (5) and were accompanied by observations of wind direction and of visibility. The concentration ranged from 0.0 to 2.5 p. p. m., the maximum occurring twice in October when there was a heavy blanket of fog and smoke and little wind velocity. Monthly averages ranged from 0.12 p. p. m. in February to 0.51 p. p. m. in December, and the average for the year was 0. p. p. m. Highest concentrations occurred in the mornings, the yearly average for the morning readings being 0.38 p. p. m. as compared with a 0. p. p. m. average for those analyses made in the afternoon.

Schade (6) has published the results of an investigation at the roof of the City-County building (163 feet above street level) in the downtown section. This work was done in 1932 from January to December, inclusive. Sampling and analyses were done essentially by the methods of Smith and Friis (7). 230 determinations were made at various times during the day from 7:00 a. m. to 4:00 p. m. The concentrations noted ranged from 0.0 to 1.1 p. p. m. sulfur dioxide, the maximum occurring in November and December. Monthly averages ranged from 0.06 p. p. m. in January to 0.21 p. p. m. in December, with a yearly average of all determinations of 0.14 p. p. m. The concentrations averaged the highest (0.17 p. p. m.) between 7:00 and 9:00 a. m. It was noted that on all days when fog cleared by afternoon there was a corresponding decrease in sulfur dioxide and that when fog did not clear the concentration increased.

ortsmouth, Va., 1926 and 1927

Quick (8) presented data on the atmosphere at the Norfolk Navy Yard for ovember 1926 and for January 1927 to September 1927, inclusive. Snap amples were drawn, the analyses being by the procedure of McKay and Ackerman 5). The maximum of any one determination was 1.3 p. p. m. sulfur dioxide, hich occurred in July and September; the minimum was 0.2 p. p. m. in Novem-er. The highest monthly average of determinations was 1.17 p. p. m. in uly, the lowest 0.48 p. p. m. in November. The average of the monthly verages for the periods was 0.97 p. p. m.

alt Lake City, Utah, 1919, 1920, and 1921

Monnett, Perrott, and Clark (9) reported sulfur dioxide concentrations n this city during December 1919, January and March 1920, and February and arch 1921. The determinations were made essentially by the method described y Wells (3). A total of 322 determinations from snap samples were made in 919-20 at various points in the heart of the city and in the residential strict. Each determination was accompanied by observations of temperature, rection and velocity of winds, and weather. The maximum concentration oted was 0.8 p. p. m. on a very smoky and foggy day, with little wind. It as found that the sulfur dioxide concentration after 12 noon was usually aller than 0.1 p. p. m.; the greatest concentrations occurring before 10 m.; that the highest concentration was observed in the business district; at smoky days showed higher concentrations than clear days; that there was inverse relationship between wind velocity and concentration of sulfur oxide; and that the average concentration during December and January was out 0.15 p. p. m. and during March about 0.01 p. p. m. Single determinaons were made from an airplane that showed 0.0, 0.2, and 0.0 p. p. m. lfur dioxide at altitudes of 1,000, 2,200, and 3,000 feet, respectively. e maximum concentration noted during February and March 1921 was 0.8 p. p. , the average being 0.03 p. p. m. for the determinations during this period.

n Francisco, Calif., 1913 and 1914

Wells and Libby (10) made 173 determinations of sulfur dioxide from snap mples at various locations during September 1913 and February and March 1914. e average of these was 0.3 p. p. m., with a maximum of 1.8 p. p. m. which curred during calm, smoky air conditions.

Washington, D. C., 1926, 1927 and 1928

Kimball and Hand (11) have reported data on sulfur dioxide determinations at the campus of the American University from November 1926 to October 1928, inclusive. The analyses were made of snap samples by the general procedure of McKay and Ackerman (5). The concentrations noted ranged from a maximum of 3.10 p. p. m. in November 1926 to a minimum of 0 p. p. m., which occurred every month. The maximum monthly average (0.54 p. p. m.) occurred in October 1928 and the minimum (0.004 p. p. m.) in August 1927. The average of the monthly averages was 0.18 p. p. m. for the 2-year period.

Pittsburgh, Pa., Philadelphia, Pa. Area, Washington, D. C., St. Louis, Mo. Area, Detroit, Mich., 1936 and 1937

The Air Hygiene Foundation of America, Inc. (12), has published the results of sulfur dioxide determinations at various points in and within a radius of 30 miles from the center of these cities from August 1936 to October 1937. All analyses were made by an iodine titration method (a modification of Smith and Friis) (7). Simultaneous analyses were made during part of the period by the electrical conductivity method of Thomas (13) (14). The measurements were made periodically at each of a large number of stations but were scheduled to give an average over all hours of the day and all days of the week. This method of investigation made it possible to summarize the concentrations in various ways, such as according to zones (with reference to the center of the city), individual station summaries, hourly concentrations, and time cycles and seasons. The tables presenting these summaries are very extensive and give many data on sulfur dioxide in the atmosphere. Tables 1 and 2 brief some of the data. Table 1 shows the average and maximum concentrations for summer, winter, and the entire year, for all stations within 5 miles of the center of these cities. Table 2 shows the average sulfur dioxide for the entire year according to zones.

Various Cities, 1936 and 1937

The Air Hygiene Foundation of America, Inc., (12) also has reported short investigations of the sulfur dioxide concentrations in other cities of the United States. These ranged from 1 day to approximately 2 months in duration, the measurements being taken at numerous locations within 5 miles from the center of the cities by the method of Smith and Friis (7). Part of the analyses were checked by the electrical conductivity method of Thomas (13) (14). Table 3 gives a brief of the data.

Panama Canal, 1927 and 1928

Quick (8) also published data on sulfur dioxide determinations made at the Panama Canal from May to October 1927 and May to September 1928. The determinations were made from snap samples and by the analysis procedure of McKay and Ackerman (5). The highest average of determinations in any one day was 1.00 p. p. m. in June 1927, the minimum 0.06 p. p. m. in June 1928. The average of the daily averages was 0.26 p. p. m. for the periods considered.

Season	Pittsburgh		Philadelphia-Camden		Washington		St. Louis-E. St. Louis		Detroit	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Winter	0.093	0.897	0.041	0.354	0.014	0.290	0.261	2.266	0.051	0.370
Summer	.060	.828	.030	.424	.003	.086	.111	1.080	.023	.228
Entire year	.078	.897	.035	.424	.009	.290	.186	2.266	.037	.370

TABLE 2. - Average sulfur dioxide concentrations for entire year, p. p. m.

Miles from center	Pittsburgh	Philadelphia-Camden	Washington	St. Louis-E. St. Louis	Detroit
0 - 5	0.078	0.035	0.009	0.186	0.037
5 - 10	.038	.021	.003	.081	.022
10 - 15	.023	.015	.001	.044	.009
15 - 20	.032	.018	.002	.031	.005
20 - 25	.016	.012	.001	.025	.006
25 - 30	.024	.011	.004	.018	.007
0 - 15	.057	.027	.007	.128	.028
0 - 30	.052	.025	.006	.101	.022

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TABLE 3. - Sulfur dioxide concentrations in various cities

City	Date	No. of stations	Total no. of tests	Ave. SO_2, p.p.m. vol.	Max. SO_2, p.p.m. vol.
Altoona, Pa.	Sept. 23, 1936	24	24	0.008	0.024
Atlanta, Ga.	Jan. 30, 31, Feb. 1, 1937	41	77	.032	.094
	May 29, 1937	28	38	.012	.069
Baltimore, Md.	Sept. 19, 20, 21, 1936	32	57	.019	.081
	Feb. 19, 20, 1937	41	53	.081	.210
	May 17 to 22, 1937	43	216	.022	.366
Birmingham, Ala.1/	Jan. 14 to Jan. 27, 1937	125	440	.017	.114
	May 31 to June 12, 1937	73	499	.017	.037
Buffalo, N. Y.	Dec. 4, 5, 6, 1936	43	56	.044	.168
Charlotte, N. C.	May 27, 1937	25	34	.015	.050
Chattanooga, Tenn.	Jan. 11, 12, 1937	46	57	.035	.102
	June 14, 15, 1937	44	78	.011	.044
Chicago, Ill.2/	Dec. 18, 19, 20, 21, 1936	88	80	.109	.402
	Mar. 25 to Apr. 23, 1937		954	.073	.549
	Aug. 6--Sept. 5, 1937	92	908	.067	1.141
Cincinnati, Ohio.	Jan. 4, 5, 1937	55	55	.064	.270
	Mar. 10, 11, 1937		66	.064	.295
	June 23, 24, 25, 1937	50	112	.021	.107
Cleveland, Ohio.	Oct. 20, 21, 1936	51	51	.029	.451
	Dec. 8, 9, 1936		54	.133	.586
	Apr. 29, 30, 1937-May 1, 1937	62	95	.064	.251
Columbia, S. C.	Feb. 2, 1937	22	25	.018	.090
Fort Wayne, Ind.	Apr. 26, 27, 1937	46	68	.028	.309
Harrisburg, Pa.	Sept. 22, 1936	26	26	.011	.037
Indianapolis, Ind.	Aug. 5, 1937	31	33	.023	.093
Johnstown, Pa.	Sept. 8, 1936	13	13	.014	.038
Louisville, Ky.	Jan. 6, 7, 1937	54	53	.049	.201
	Mar. 8, 9, 1937		59	.032	.14
	June 21, 22, 1937	50	77	.022	.11
Nashville, Tenn.	Jan. 9, 1937	28	29	.093	.21
	June 17, 18, 19, 1937	35	113	.028	.11

1/ Includes Bessemer, Ala.

2/ Includes Gary, Ind.; Whiting, Ind.; East Chicago, Ind.; and Hammond, Ind.

(Continued)

TABLE 3. - Sulfur dioxide concentrations in various cities (continued)

City	Date	No. of stations	Total no. of tests	Ave. SO_2, p.p.m. vol.	Max. SO_2, p.p.m. vol.
.chmond, Va.	Feb. 3, 4, 5, 1937	53	78	0.047	0.261
	May 24, 25, 1937	56	74	.009	.025
ringfield, Ill.	Sept. 7-11, 1937	32	171	.021	.169
ledo, Ohio.	April 28, 1937	29	30	.023	.072
eeling, W. Va.[3]	Aug. 3, 1937	30	33	.070	.320
ungstown, Ohio.	Oct. 19, 1936	26	26	.026	.123
	May 3, 4, 1937	45	69	.049	.162

Includes Martins Ferry and Bellaire, Ohio.

Cities of Europe

lin, Germany, 1922, 1931, 1937

Liesegang (15) investigated the air in the vicinity of Berlin. He deter-
ed the sulfur by exposing a filter-paper shell soaked with a solution of
assium carbonate in water and glycerin to the air for 100 hours and analyzing
material on the shell at the end of the period. He reports that the sulfur
orbed in 100 hours averaged 10 mg. during winter months at Berlin-Dahlem,
outskirts of the city, and that under certain conditions this figure rose
ve 20 mg. The filter-paper shell was approximately 75 mm. in diameter by
mm. in height.

Schikorr (16) also obtained data on the sulfur gases in the air at Berlin.
measurements, using Liesegang's method of absorption cylinders, were made on
roof of the State Board of Testing Materials in Berlin-Dahlem and in
ewald, a forest 7 kilometers away, during the 15 months from October 1935 to
ember 1936, inclusive. He noted decided seasonal fluctuations. In Berlin-
em the ratio of winter value to summer value went as high as 10:1, and in
forest 4:1. Values in Berlin-Dahlem ranged from approximately 9 to 90 mg.
ur per 100 hours, with an average of 39, while in the forest the minimum,
mum, and average were respectively 4, 14, and 9 mg.

Haehnel (17) has published information on the sulfur dioxide concentration
erlin, expressed as p. p. m. Air samples were drawn through concentrated
tic potash for about an hour or longer on each of 5 days in March and April
the sulfur dioxide determined gravimetrically. Each sample was taken at a
erent time of the day on a roof 20 meters above the street, 8 meters from
closest chimney, and during weather conditions ranging from clear to misty
. An average concentration of 11.2 p. p. m. is reported, but Haehnel
tions whether Berlin air contains such high sulfur dioxide at all times and
es.

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Budapest, Hungary, 1932, 1933, and 1934

Waldbauer (18) studied the air at a number of locations in this city. About 300 sulfur determinations were made over a period of 20 months, from October 1932 to May 1934, inclusive. The analysis method was similar to that used by Liesegang (15). The concentrations in the air, as indicated by this method, are given in table 4. The values range between 3 and 45 mg. absorbed in 100 hours, being lowest in summer and highest in winter months.

Liege, Belgium, 1936

Batta and Leclerc (19) have noted values for the sulfur dioxide content of the atmosphere in Liege. These ranged from 0.2 to 1.8 p. p. m.

London and Suburbs, England, 1923-27

Reynolds (20) made almost continuous measurements of sulfur dioxide for about 4 years in the atmosphere at Plaistow and Upminster, which are 5 and 15 miles, respectively, from the center of the metropolitan area. He drew large samples (7,000 to 25,000 liters) of air during 3- to 10-day periods, absorbing the sulfur dioxide in dilute sodium bicarbonate, acidifying and oxidizing with bromine water or bichromate, and estimating the sulfur dioxide as barium salt by comparing with solutions containing known amounts of 0.00 sulfuric acid. Records were kept of rainfall, wind direction, visibility, and temperature. The concentration at Plaistow was found to average about six times that at Upminster. The average during a winter week with consider fog was 0.4 p. p. m. A low summer figure was 0.08 p. p. m. Reynolds' conclusions were that appreciable quantities of sulfur dioxide were brought to the sampling points by winds from the center of the city; that factory stac were responsible for a large portion of the sulfur dioxide; that the concentrations were higher in winter than in summer; and that maximum amounts were reached during winter fogs when upward and lateral convection currents were least noticeable.

Time	Inner City (closely settled district)			Neighborhood of railroad stations		Villa Quarter (not thickly populated, winds from the river)			Hygienic and Bacteriological Institute of Budapest (outside city in region of several central heating plants and many heating stoves
	Szervit Place	University Place	St. Stephans Place	West Station	East Station	Rose-hill	Blocksberg	Szechenyi-Bad (near low chimney from bad heating stove)	
1932									
October	22.9	-	-	21.6	23.5	8.8	13.1	27.5	14.3
November	23.4	-	-	19.0	19.6	-	11.8	25.0	17.2
December	27.0	-	-	23.5	19.7	7.4	12.2	29.6	18.9
1933									
January	27.0	20.6	28.7	31.9	30.0	12.5	16.2	27.5	24.0
February	21.6	18.5	22.4	23.6	22.5	9.4	12.2	25.0	19.2
March	25.3	16.2	19.2	21.2	19.4	8.8	9.5	22.0	16.0
April	17.6	17.5	19.6	20.6	18.0	8.0	8.9	19.0	14.8
May	19.0	19.7	16.2	17.6	15.4	6.8	9.1	17.3	11.5
June	9.7	8.5	9.2	10.6	9.7	6.8	8.0	16.8	9.5
July	8.0	6.0	7.0	8.4	8.0	6.2	7.0	17.8	7.5
August	5.5	3.5	4.0	5.8	5.1	2.7	3.1	21.0	5.8
September	6.9	7.1	6.8	9.5	10.8	4.0	3.4	22.5	8.0
October	-	-	-	-	-	-	-	20.5	12.0
November	20.1	21.4	20.0	25.0	27.0	13.0	15.3	24.8	18.0
December	35.5	35.1	39.2	33.7	33.4	18.9	19.0	32.4	28.5
1934									
January	28.9	37.8	44.5	31.0	32.4	15.7	20.2	26.0	24.0
February	31.1	35.1	39.1	36.2	36.8	8.1	14.2	26.0	27.0
March	21.6	23.1	30.0	24.6	25.0	9.5	12.1	21.5	19.0
April	20.0	14.8	20.0	21.9	17.2	6.7	9.0	18.8	14.0
May	10.6	8.8	10.8	13.5	10.7	6.7	9.8	26.0	12.0

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Cities of Great Britain, 1932-37

Determinations of sulfur dioxide have been made by investigators working in cooperation with the British Government through its Department of Scientific and Industrial Research. These have been made from 24-hour continuous samples taken at fixed locations and analyzed by the method reported by Ellis (21). McLachlan (22) has tabulated the yearly averages found in 14 cities from 1932 to 1936. These range from a minimum of 0.035 p. p. m. in Cardiff in 1932 to a maximum of 0.194 p. p. m. in Newcastle during the same year. A majority of the figures (approximately 70 percent) are above 0.1 p. p. m. The yearly averages and additional data for a more recent year, April 1, 1936 to March 31, 1937, were (23) as shown in table 5.

TABLE 5. - Sulfur dioxide concentrations in Great Britain April 1, 1936 to March 31, 1937, p. p. m.

Station	Yearly average	Daily average	
		Minimum	Maximum
Glasgow - Trongate	0.096	0.017	0.410
Greenwich - Royal Observatory	.056	.004	.262
Kingston-upon-Hull - City Laboratories	.063	.013	.329
Leicester - Grey Friars	.078	.012	.315
London - Chelsea, Lots Road	.090	.009	.316
Westminster Bridge - County Hall	.123	.012	.381
Westminster City Hall	.115	.035	.293
Newcastle-on-Tyne - Dean Street	.111	.04	.39
Salford - Regent Road	.055	.000	.470
Sheffield - Surrey Street	.148	.035	1.676

Values for the sulfur in the air have also been obtained for a number of years by another method, basically similar to that used by some investigators in Europe. This procedure (24) is to expose small cylinders coated with lead peroxide paste to the atmosphere for about a month, after which the paste is analyzed and the results reported as milligrams sulfur trioxide per 100 sq. cm. of cylinder area per day. The values obtained in this way in 1936 and 1937 were (23) as shown in table 6.

Prague, Czechoslovakia, 1929 and 1930

Landa (25) has reported determinations of sulfur dioxide in the air at Prague, analyses being made by passing the air through 3 percent hydrogen peroxide and measuring sulfur dioxide gravimetrically and by titrating. The values are as follows:

Month	SO_2, p.p.m.	Month	SO_2, p.p.m.
February	0.37	October	0.02
March	.13	November	.13
May	.02	December	.13
June	Trace	January	.13
September	0		

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TABLE 6. - Sulfur Measurements by lead peroxide method, mg. sulfur trioxide per 100 sq. cm. per day

Station	Average for year	Station	Average for year
arnsley		Rotherham	3.42
Kendray Hospital	3.45	Salford	
Mount Vernon	2.78	Ladywell Sanatorium	4.72
ardiff		Regent Road	4.57
City Hall	1.09	Sheffield	
Splott	2.83	Dore	.98
agenham	1.54	Ewden Waterworks	1.04
ewsbury	1.92	Handsworth	2.90
dinburgh	.49	Surrey Street	3.37
arston (Herts)--Building		Stoke-on-Trent	3.06
Research Station	.55		
lasgow--20, Trongate	2.65		
alifax			
Wade Street	3.30		
West View Park	2.20		
uddersfield	2.22		
ingston-upon-Hull	2.72		
eeds			
Headingley	1.82		
Park Square	2.95		
eicester			
Aerodrome	.83		
Bentleys	2.41		
Central Avenue	.65		
Grey Friars	2.69		
Humberstone	1.17		
Town Hall	2.93		
ndon			
Chelsea, Lots Road	3.97		
Westminster Bridge	5.60		
City Hall	3.41		
Horseferry Road	2.92		
Mount Street	3.24		
H.M.O.W. East	3.76		
H.M.O.W. South	3.80		
mington	.25		
nchester			
Oldham Road	5.23		
Withington	2.22		
York Place	3.00		
wcastle-upon-Tyne	3.21		
thamsted	.58		

Austria, 1928

Bamberger and Nussbaum (26) have done some work on the dispersion of sulfur dioxide in the atmosphere from an established source. They determined the sulfur dioxide by exposing absorbent cotton goods wet with a solution of potassium carbonate in water and glycerin for 100 days and analyzing the material on the cloth at the end of the period. These investigators found evidence indicating that in general the amount of sulfur dioxide in the air is a function of the elevation and the distance from the source, the sulfur dioxide found being less as either of these variables increased.

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